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The ALBE Gridded Visibility Model

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The AirLand Battlefield Environment (ALBE) visibility model provides a new method of calculating Line-of-Sight visibility products derived from digital terrain elevation data. This new method uses a gridded raster approach rather than the historical vector approach. The basic principles and assumptions behind the model are discussed, starting with the advantages and disadvantages of using the gridded versus a vector approach. New methods devised to handle the gridded approach are discussed, including how to determine the grid cell resolution, the spacing between individual radials, and a detailed look at determining the spacing between individual points along a radial. A new method that uses a unique step size for each individual radial is described in detail. Other features covered are the earth's curvature, the inclusion of vegetation data, the visual acuity, and an elevation matrix form to help select a precise observer location. Finally, other closely related models that are based on the basic visibility model are discussed, including How High to Visibility, Radio Frequency Loss, Visibility Probability, Line of Sight for Obstacles, Aerial Detection, and Helicopter Approach Zones.

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CONTENTS

ILLUSTRATIONS

PREFACE

This work was funded under DA Project 4A263734DT08, "AirLand Battlefield Environment Technology Demonstration Program."

This work was performed during the period January 1991 to July 1993 under the supervision of Mr. Jerry Breen, Chief, Terrain Integration Branch, and Mr. Bruce Opitz, Director, Geographic Sciences Laboratory. Also, TEC members directly contributing to the ALBE program and the development of the gridded visibility model were Joni Jarrett, Charlie Gage, Vinh Duong, Kevin Slocum, Mark Kerschner, Todd Blyler, and George Newbury.

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THE ALBE GRIDDED VISIBILITY MODEL

INTRODUCTION

The ability to determine quickly which areas of the battlefield are visible from an observer and which areas remain hidden has long been a critical task for the military. Various line-of-sight algorithms that use digital terrain elevation data have been developed over the years to calculate visibility, most of them providing their graphical output in a vector format. A newly developed visibility algorithm based on a gridded raster approach has been developed as part of the AirLand Battlefield Environment (ALBE) technology demonstration program.

This report will describe the basic underlying concepts and features used within the ALBE visibility and other similar models. It is hoped that with a better understanding of these concepts and why they were chosen, future developers will be able to build the most optimal algorithms in regards to performance, speed and accuracy.

The ALBE technology demonstration program was initiated by the U.S. Army Corp of Engineers to provide topographic and environmental expertise in the form of graphic map overlays produced by a variety of tactical decision aid software models. Participating Corps of Engineers laboratories included the Cold Regions Research and Engineering Laboratory (CRREL), the Waterways Experiment Station (WES), and the Topographic Engineering Center (TEC); and the Army's Battlefield Environment Directorate (BED). The TEC scientists used an initial visibility algorithm provided by the Electromagnetic Compatibility Analysis Center (ECAC) at Annapolis, MD as a foundation for the further enhancements presented in this report.

The basic visibility algorithms consist of sending a series of radials from a centrally located observer out to a specified observation distance. At set distances along each of these radials, geometric calculations are performed to calculate the angle between the observer and the target. Angles between the observer and terrain points along the radial are also computed. When the observer-to-terrain angle along the radial is greater than the observer-to-target angle, the target is defined as hidden from the observer and visibility does not exist. This concept, shown in Figure 1, provides the basis for many visibility algorithms. A line-of-sight analysis by Jarrett (TEC) and Riding (DBA) identified and described the differences among various Army visibility models. Recommendations from this study were incorporated into the ALBE visibility model.

VECTOR vs GRIDDED APPROACH

The ALBE visibility model went through considerable changes during the history of the ALBE program. The original model's output consisted of spoked vectors extending from a central observer point. User inputs usually consisted of an observer location, observer and target heights, an observation limit (how far you are looking out), a radial step size (distance between elevation heights along a radial), and a distance between radials (i.e. number of degrees of spacing). Default values are often used for these inputs. Output had been traditionally displayed as vectors drawn along each of the calculated spoked vectors. Although this provided a quick and easy way to display results, it had several disadvantages associated with it.

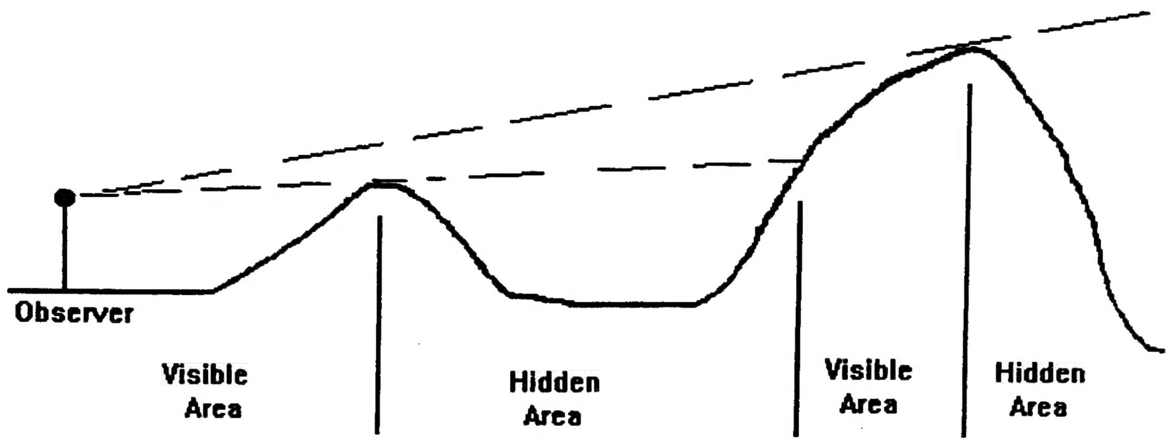

Figure 1. Cross-Section of a Typical Line-Of-Sight Profile.

1. The vectors are concentrated near the center observation point. A single elevation posting near the observer location may have several spoke radials going through it, while an outlying point may have only one or no radials going through it. This implies to the user that there is a greater concentration of elevation postings near the observer, while in truth the elevation postings are equally distributed across the entire area. The density of vectors near the observation point also has a tendency to obscure essential information being displayed underneath the vectors.

2. When performing quantitative analysis on the LOS results (i.e. calculating the percentage of visible regions versus hidden regions), the results can be easily skewed so that the points near the center are overemphasized. Each of the radials passing through a single elevation posting marked as "visible" would also be classified as "visible," creating an undesired multiplier effect. An outlying point marked as "hidden" with a single intersecting radial would be counted only once. Even though the two points represent equal areas, care must be taken to assure that one is not given higher preference than the other.

3. If the spacing between the radials is too large, elevation postings near the limit of observation, or at the viewing circle's edge, may not be included in the Line-of-Sight (LOS) analysis, even though they are within the area of interest. This sparse representation implies that these postings are not critical to the LOS analysis.

4. With the radial spoked output, it becomes very difficult to combine, compare, or quantify digitally the outputs from two different LOS plots or to use the LOS output as a layer of information within another model.

The ALBE software developers decided to develop a method to calculate visibility where each elevation position would be assigned either a "hidden" or "visible" value. Since Digital Terrain Elevation Data (DTED) source data is in a raster gridded format, LOS output was changed to a raster format so it would maintain the integrity and resolution of the DTED. The ideal solution would be to provide an output raster format with the same grid sizes as the DTED data, providing a true one-to-one correspondence. This type of gridded raster output has several advantages.

1. The output closely conforms to the resolution of the original source data.

2. An equal distribution of raster cells exists throughout the entire analysis area. There is no longer a concentration of vectors near the center observer site.

3. Since each output raster cell covers an equal area and has only a "hidden" or "visible" value associated with it, analysis of the results becomes much easier and less error prone.

4. It becomes much easier to combine, compare, or quantify digitally the results from nearby LOS plots or to send the results to different systems for further use or analysis. It also becomes easier to use the results as an additional layer of information for use by other models or systems.

The only immediate disadvantage found with using the gridded raster approach was that it requires much more internal data storage to store and process data, especially when looking out at long distances. Since most visibility calculations within ALBE were done for distances under 10 km, this did not cause major problems.

METHODS

Grid Cell Resolution

The first decision to be made when using the new gridded format was determining the grid cell size resolution. Many users and developers assume incorrectly that DTED Level I data is evenly spaced about 100 meters apart throughout the world, when in actuality the elevation postings are 3 arc-seconds apart. This means that the distances between elevation postings actually get closer to one another as one approaches the Poles from the equator. At the equator, elevation postings are approximately 90 meters apart from each other in both the north-south and east-west directions, as shown in Figure 2. The total area contained between four neighboring postings is approximately 8,100 square meters.

At just below 50 degrees north latitude, the distance between east-west postings has shortened to approximately 60 meters, giving a total area between neighboring elevation postings of approximately 5,400 square meters. This is shown in Figure 3.

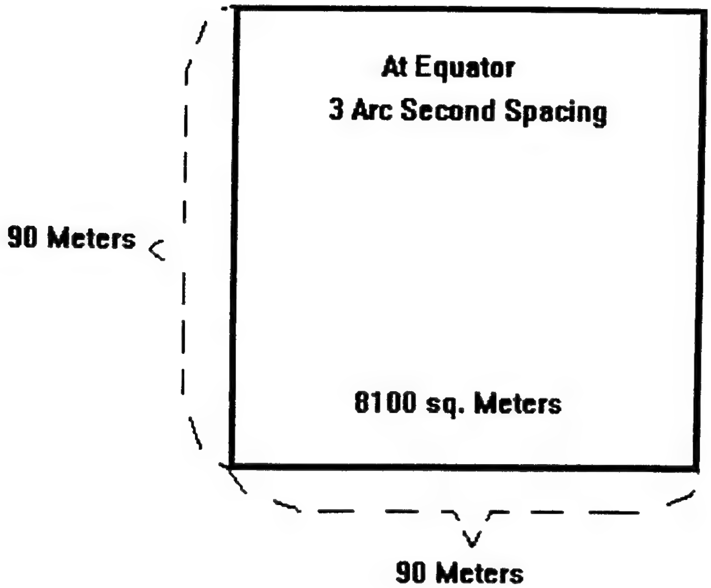

Figure 2. DTED Spacing at the Equator.

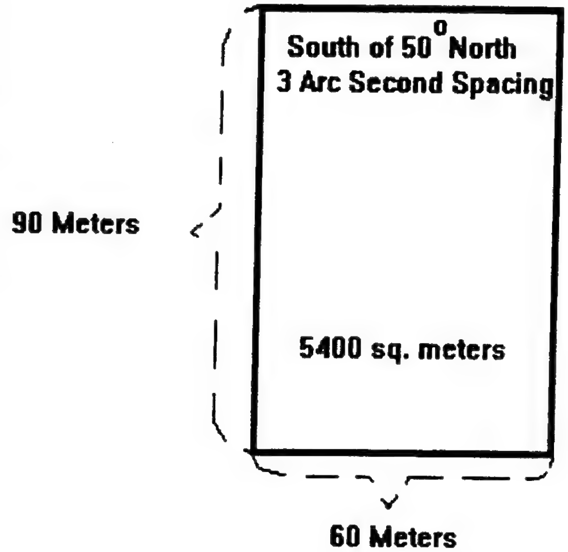

Figure 3. DTED Spacing Just Below 50 Degrees North Latitude.

At 50 degrees latitude, the spacing between postings in the east-west direction changes from 3 arc-seconds to 6 arc-seconds. As a result, the spacing between postings in the east-west direction is now approximately 120 meters, giving a total area between neighboring postings of approximately 10,800 square meters (See Figure 4). Further changes in DTED spacing occur at 70, 75, and 80 degrees latitude.

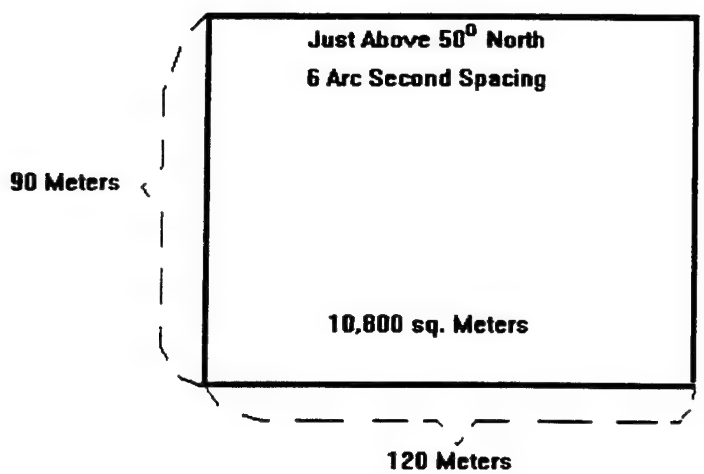

Figure 4. DTED Spacing Just Above 50 Degrees North Latitude.

This varying of distances between elevation postings will occur no matter what level of DTED resolution is being used. Using DTED Level II will change the distances between elevation postings from about 90 meters to 30 meters. The distances between postings will still vary, although the variances will be much smaller. The remainder of this report will assume that distances and values from DTED Level I are being used.

Because of this variance between elevation postings, a single grid cell size would not be able to support accurately the entire globe. The ALBE visibility model adjusts the size of its own grid cells to match the size of the underlying DTED grid size at the center observer's position. This provides a close one-to-one correspondence between the internal data storage grid cell size and the actual underlying DTED data.

Spacing Between Radials

Another consideration when using a grid cell approach for visibility is what the spacing should be between successive radials. Most vector algorithms use radial spacing with 1, 3, or 5 degrees of spacing. Within the ALBE model, radials are spaced so that each grid cell located on the outer periphery of the raster grid area is visited or touched at least once. Grid cells inside of this periphery region may be visited by more than one radial. Having too few radials results in untested grid cell conditions, while having too many radials results in redundant work being performed. Radial spacing is determined by the angle formed between the minimum dimension of the grid cell and the distance limit of observation, as shown in Figure 5. As the distance limit of observation increases, more radials are needed to assure total coverage of all grid cells.

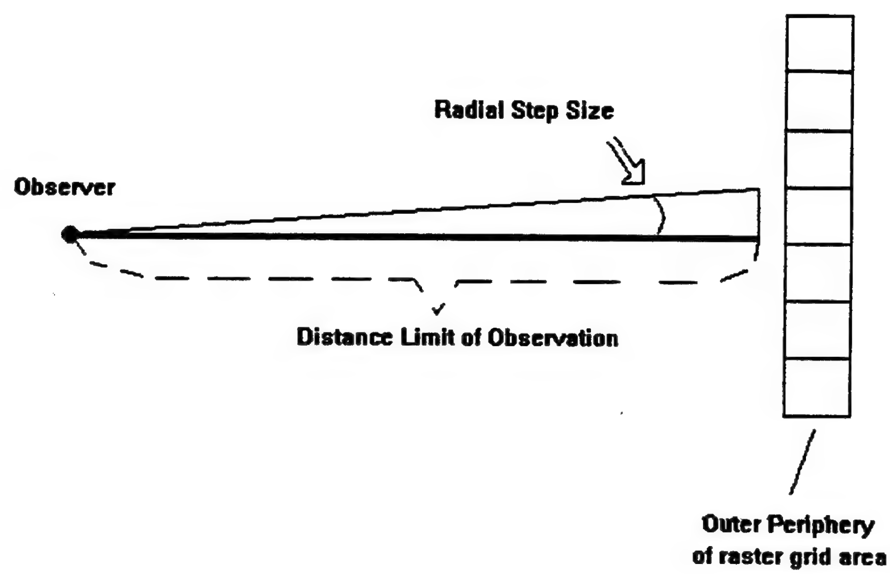

Figure 5. Determining Spacing Between Radials.

Spacing Along Radials

All visibility algorithms must determine what the step increment value should be along each radial. This step increment value determines the locations where elevation values are obtained to be used in the visibility calculations. Many algorithms use a step value of 100 meters because of the incorrect assumption made about DTED post spacings. As was previously shown, the actual spacing between DTED postings can vary widely depending on latitude.

If the step increment value is too large, certain elevation values along the radial are skipped. These skipped values may be critical if they reflect relative maximum values along a radial. Skipped values may result in hidden areas being misclassified as visible.

In Figure 6, the large dots represent the locations where elevation values are obtained. A step increment that is too large is shown, resulting in the peak elevation of the first hill being skipped completely. The result is that the computed line-of-sight is now lower than it actually should be, meaning that the second hilltop is now incorrectly classified as visible.

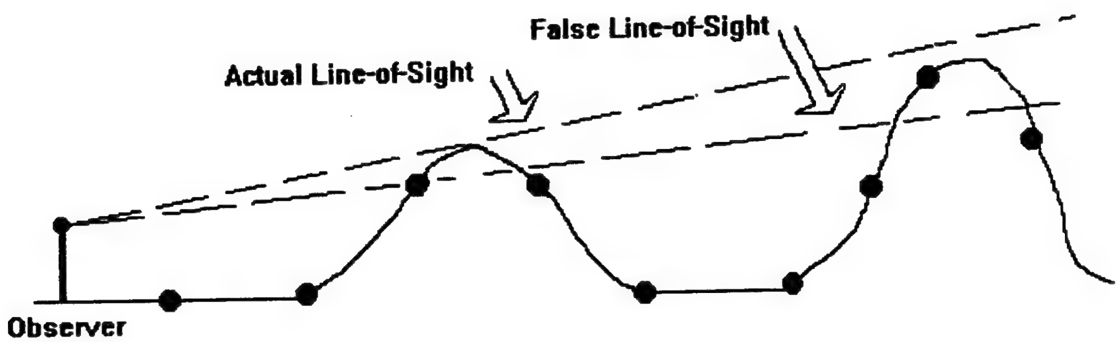

Figure 6. Too Large of a Radial Step Increment Will Result in Skipped Elevation Postings.

If the step increment value is too small, a different problem occurs. Because DTED Level I is made up of unique elevation postings spaced approximately 100 meters from one another, a method must be used to fill in for the missing elevation values between the given DTED postings. The ALBE visibility model makes the assumption that a single elevation posting will represent the elevation for the area surrounding that posting. Figure 7 illustrates both a simplified cross-section of an actual hill and the representation of this hill as represented by a series of artificial elevation values. Because of the 100-meter resolution constraint of DTED, the hill now appears in a stair-step manner.

Elevation values are obtained at defined distances along a radial. Ideally, each elevation value along a radial would be read once, as shown in Figure 8. The dots represent the points along the radial where elevation values are obtained. This produces a correct result with no hidden areas on the hillside.

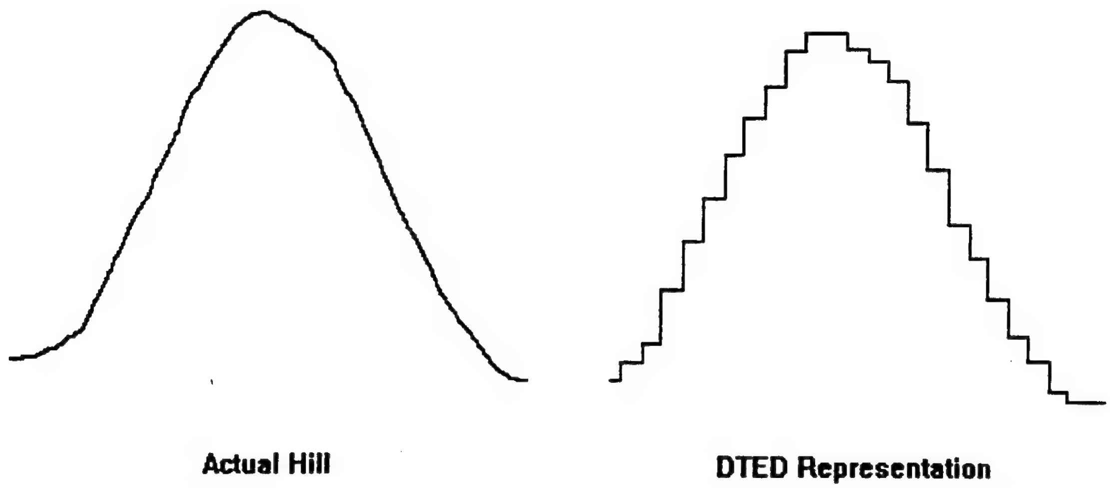

Figure 7. Actual and DTED Representation Profiles of a Simple Hill.

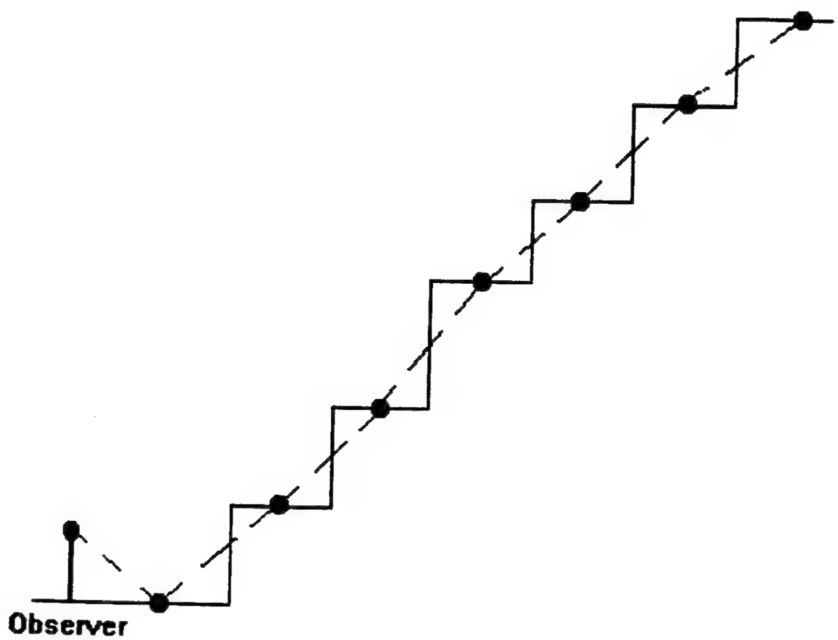

Figure 8. With Proper Spacing, Elevation Values Are Accessed Only One Time.

If the step increment value is too small, as in Figure 9, certain elevation values may be read more than once. This will result in false "hidden" areas being calculated. When viewed from an overhead perspective, this area appears to have a striped, or "washboard" effect, fluctuating between "visible" and "hidden" values.

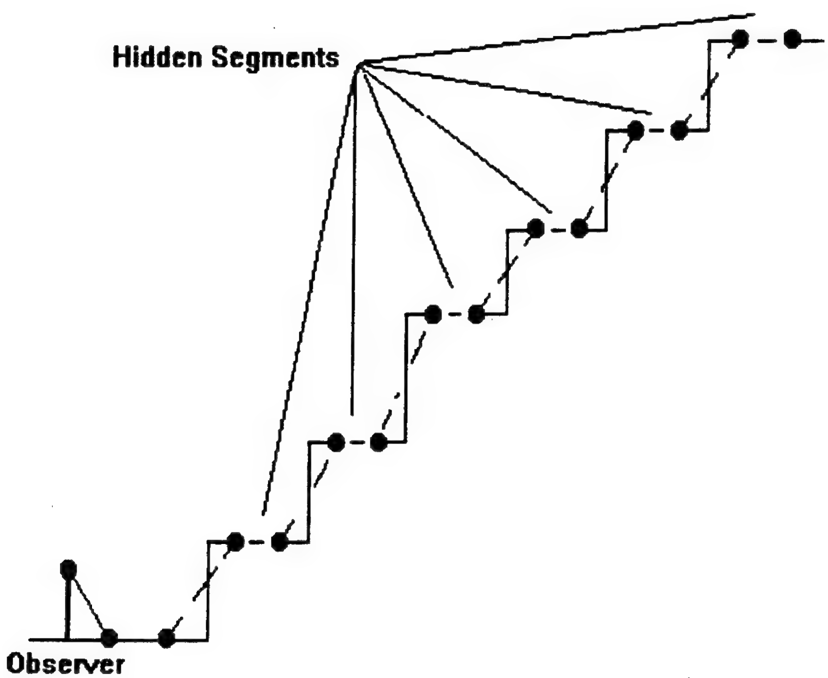

Figure 9. Accessing Elevation Values Twice May Result in False Hidden Areas.

This problem of reading the same elevation posting twice becomes especially critical when an observer is placed at the top of a hill. In Figure 10, a small step increment results in the peak elevation value being read twice, creating a false "stairstep" at the peak. The observer must look over this "stairstep" to see the underlying elevations. This results in a large section of the lower elevations being incorrectly classified as 'hidden.'

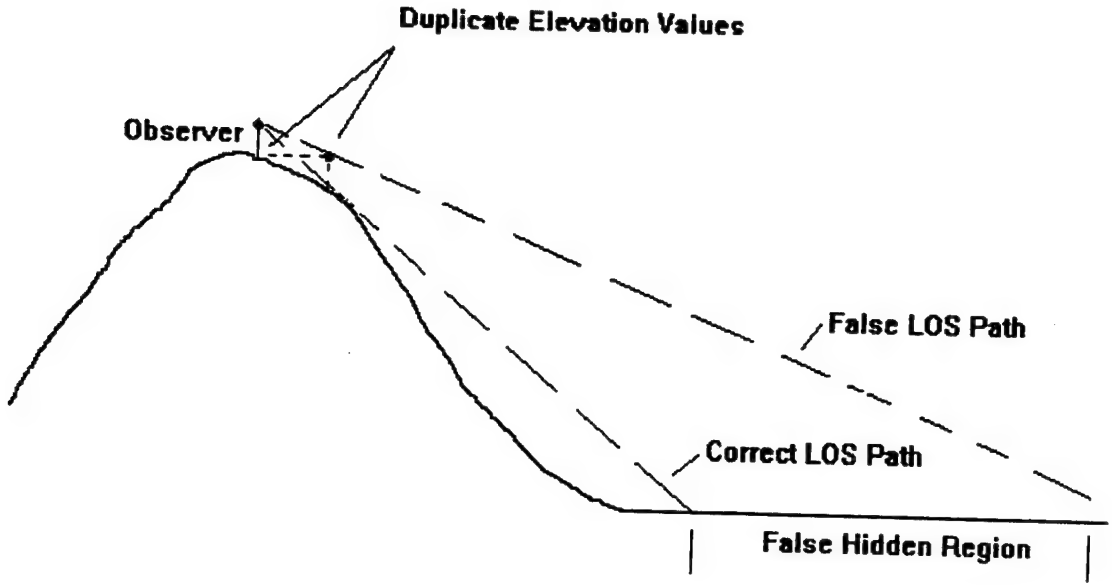

Figure 10. Incorrect Spacing at Hilltop May Result in False Hidden Areas.

Numerous visibility algorithms resolve these step increment problems by using a bilinear or other type of interpolation to obtain elevation values while stepping out along a radial. These interpolation methods consist of an "averaging" or "smoothing" of the nearest elevation values to obtain a new unique elevation value. This is one way of removing the possibility of obtaining identical elevations along a radial.

For various reasons, this type of interpolation within the ALBE visibility model was not used. The first reason was that interpolation implies creating new data that wasn't originally there, which goes against the earlier philosophy of having a one-to-one correspondence between the raster grid cells and the original DTED data. The second reason was that interpolation methods are computationally expensive, especially when considering that elevation values must be interpolated for every step increment along every radial. A third reason was that a new method was developed to obtain elevation values along a radial, which appears to have solved the above problems.

Rather than using one constant radial step size throughout the entire area, one can use this new method to calculate a different step increment value for each unique radial or azimuth. This radial step size is set to the minimal distance required to access a different unique cell value along the radial. This distance is calculated by following the azimuth out from the bottom left corner of a single grid cell area and measuring the distance where it crosses the cell boundary. At just below 50 degrees latitude, an observation radial in the north-south direction would have a step size of 90 meters, while an azimuth in the east direction would have a radial step size of 60 meters. As shown

in Figure 11, diagonal azimuths would have step increment values ranging from 60 to 110 meters.

Just above 50 degrees, where the elevation post spacing changes to 6 arc-second intervals, the possible step increment values would range from 90 to 150 meters. This is illustrated in Figure 12.

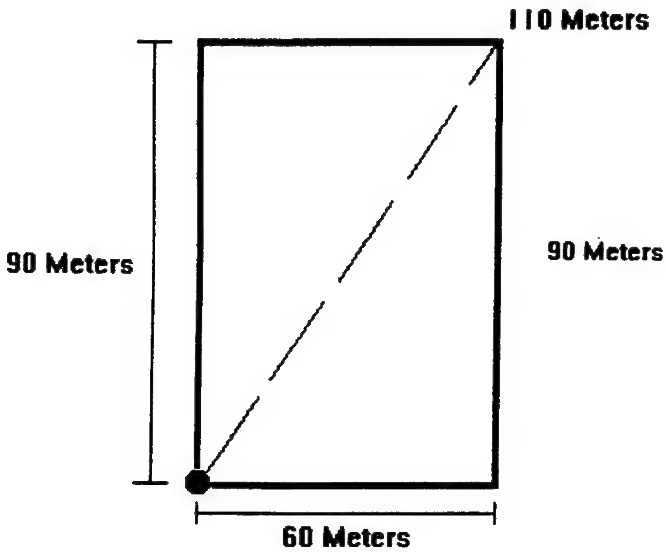

Figure 11. Just Below 50 Degrees N, Radial Step Sizes Range From 60 to 110 Meters.

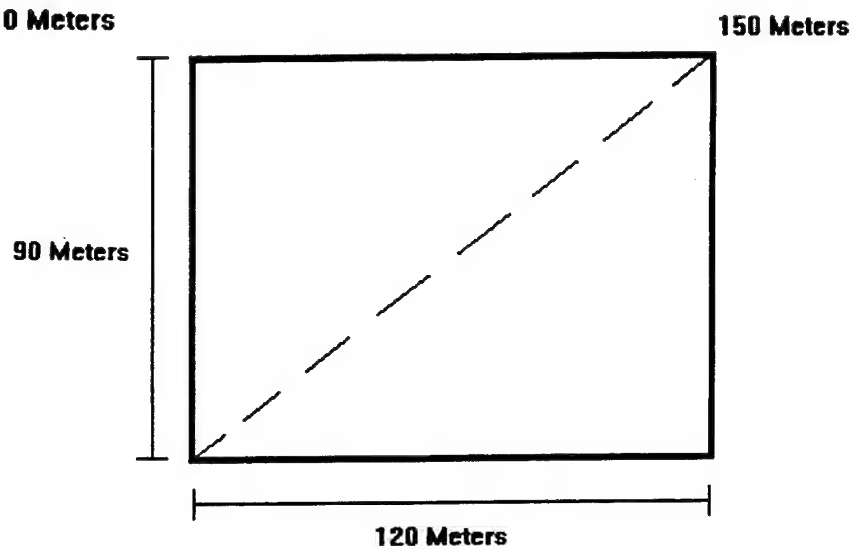

Figure 12. Just Above 50 Degrees N, Radial Step Sizes Range From 90 to 150 Meters.

This variable step size approach has several advantages. It minimizes the risk that elevation values will be either skipped or accessed twice, eliminating many of the previously discussed problems. Interpolated elevation values no longer need to be calculated at every step along each radial, resulting in a faster processing time. Because some radial step sizes may now reach values up to 150 meters, fewer calculations are needed as compared with the previous constant radial step size of 100 meters. The only additional calculation is at the start of each radial to determine the unique step increment value for that radial.

Multiple Grid Cell Hits

A consequence of using a gridded raster approach is that many of the raster cells, especially those closest to the center observer location, may have more than one radial intersecting it. This results in having to decide whether a particular cell should be classified as either "hidden" or "visible." Figure 13 represents grid cells with their respective elevation value, along with two line-of-sight radials. The upper right cell value would be classified as "hidden" when looking out along the upper radial, but classified as "visible" when looking out along the lower radial.

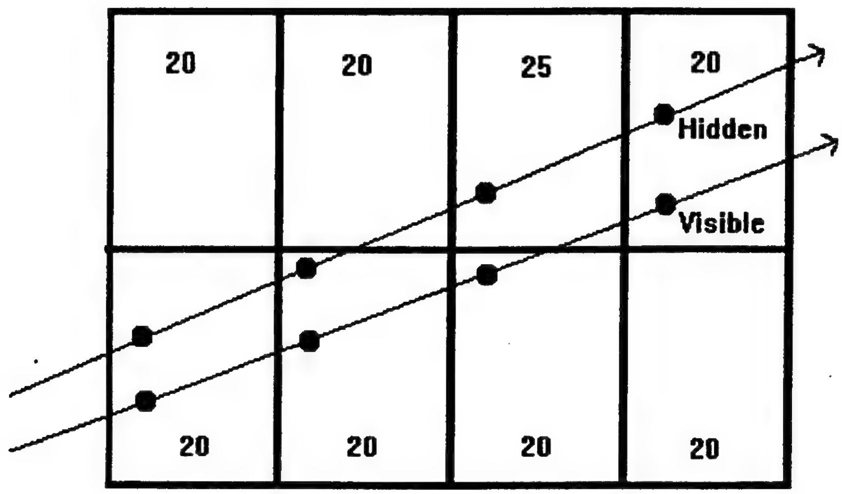

Figure 13. Upper Right Cell May Be Marked As Either Hidden Or Visible.

An early version of the ALBE gridded visibility model gave the user, through a form choice option, the choice of which of the two "visible" or "hidden" values should have precedence. Because the typical ALBE user found the explanation behind this form choice confusing, the form choice option was eliminated and the software hardcoded to a "visible" priority. It may be practical in the future to base this priority on the type of application for the visibility analysis: a friendly observer analysis may want to emphasize the 'visible' option, while an enemy observer analysis might want to emphasize the 'hidden' option. Still another possibility is to keep count of the hidden/visible hits for each cell and give priority to the one with the higher count value.

Subsampling of Data at Large Distances

A problem mentioned earlier was that the internal data storage requirements are much greater when using a gridded raster approach. As the distance limit of observation increases, more and more raster grid cells are needed to store information and results. At a distance of roughly 10 kilometers, the ALBE system was not able to handle this large volume of data. Because visibility calculations were occasionally required beyond this distance, an approach was needed to provide coverage at these longer distances. On other hardware systems, using different software, one may not experience the same type of limitations and therefore may not need to perform the following corrective measures.

The ALBE system doubles the initial grid dimensions in both the x and y directions when the distance limit of observation exceeds 10 kilometers, resulting in a larger grid cell size. These dimensions are also doubled at distances of 20, 40, and 80 kilometers. The elevation data is also subsampled at these distances, raising the possibility of skipping key terrain points. Because certain elevation postings are ignored when performing line-of-sight analysis at these long distances, the ALBE visibility model warns the user when this occurs. The user is presented with the distances between the subsampled elevation postings and warned to treat the results with caution.

The ALBE visibility algorithm does not currently support the increased resolution of DTED Level II data, but it should not be difficult to modify the code to accept it. The main change needed would involve using shorter distances before the grid dimensions are doubled. The distances where these changes occur have yet to be calculated.

The issue of subsampling of data at large distances was necessary because of software and hardware limitations associated within the ALBE system. Other hardware systems using different software may not experience the same type of limitations and may not need to perform these corrective measures.

Earth's Curvature

The ALBE visibility model does take into consideration the curvature of the earth. The earth's curvature is based on the WGS 84 semi-major axis length. Elevation values at each step interval for each radial are adjusted downward by subtracting the appropriate earth-curvature effect. This effect, shown in Figure 14, becomes more pronounced as one moves further away from the observer. The corrective loss due to curvature is roughly 2 meters at 5 kilometers, 8 meters at 10 kilometers, 31 meters at 20 kilometers, and approximately 200 meters at 50 kilometers.

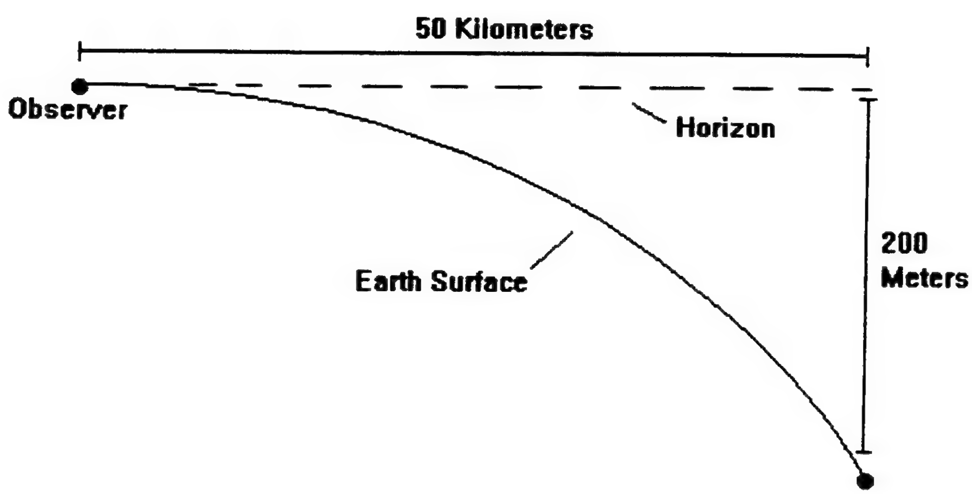

Figure 14. Effects of the Earth's Curvature.

Influence of Vegetation

The ALBE model accesses Defense Mapping Agency's Interim Terrain Data (ITD) vegetation height data when calculating visibility. These vegetation heights are not added to the ground elevations. A study done by Slocum (1993) concludes that "DTED cannot be counted on to reflect accurate ground elevation in areas of vegetation." It is virtually impossible to tell whether or not the elevation data includes vegetation heights. The ALBE visibility model compares the observer height to the vegetation height at the observer location. If the vegetation height is greater than the observer's height, the user must either raise the observer height above the vegetation, choose another observer location, or exit the program. Target heights go through a similar process. If the vegetation height at the target location is taller than the actual target height, as shown in Figure 15, then that location is marked as "hidden." This may result in cases where the observer is facing a forested hillside; yet no visibility exists because the target resides under the forest canopy.

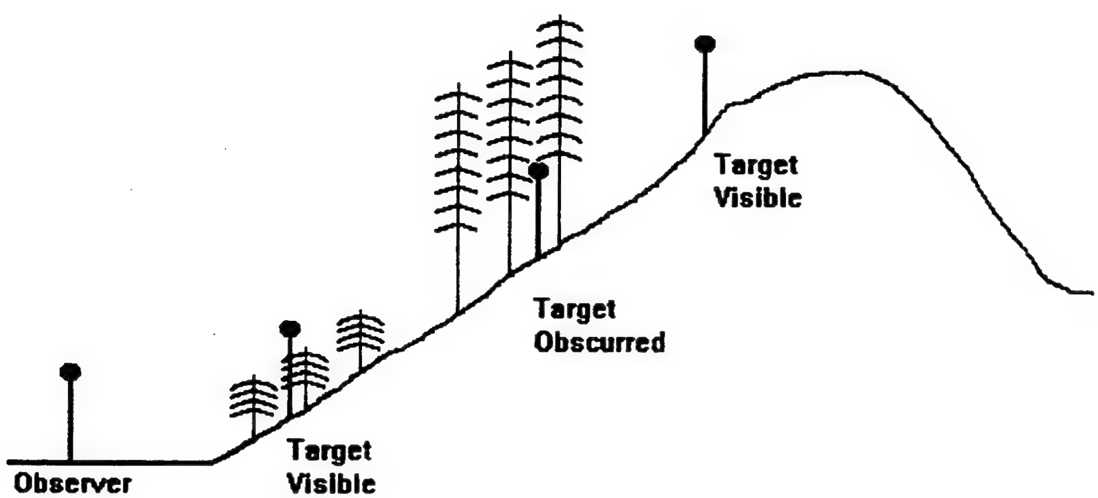

Figure 15. Vegetation Is Compared With Observer and Target Heights.

Vegetation heights are ignored when calculating the angles to determine visibility. No calculations are done to consider whether the observer can see beyond the "shadow zones" created by vegetation. Thus, the area immediately beyond a forested region may be classified as having visibility.

Although it would be possible to incorporate vegetation heights into the line-of-sight geometry calculations, they were not included in the algorithms at this time. There are too many questions

concerning the cumulative errors on visibility when considering the inherent inaccuracies contained within both the elevation and vegetation data sets.

Visual Acuity

The ALBE visibility model includes a very rudimentary visual acuity algorithm. The user is prompted to enter a minimum target dimension. This dimension must subtend at least 1 minute arc of the observer's view to be considered visible, as shown in Figure 16. When the target is moved to a distance where this condition becomes false, visibility no longer exists.

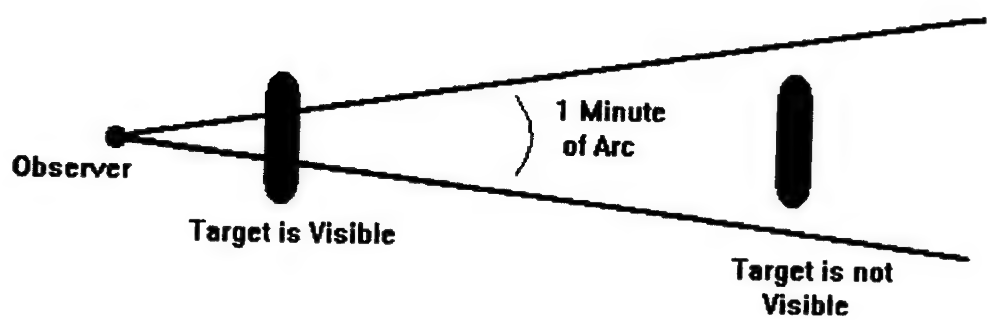

Figure 16. Objects May Become Hidden At Large Distances Due To Visual Acuity.

Elevation Matrix Form

Another feature of the ALBE visibility model is what is called an elevation matrix form. The user has the option, after selecting an observer location, of viewing a form giving a 5 by 5 matrix containing the 25 elevation values centered around the selected observer location. The user can choose one of the nearby higher elevations or "walk" through the elevation database to get to a user-defined observer location. This feature was added because the resolution differences inherit in the various data sets (DTED, map background, input coordinate locations, etc.) do not precisely align with each other. For example, a user may try to select an observer location by clicking on what appears to be a hilltop on the map background image. If the hilltop elevation value contained in the underlying DTED is not aligned with the map background, the observer will be positioned on one side of the hill, unable to see any of the areas located on the other side. The elevation matrix provides an easy way to assure that optimal results are gained by choosing the correct observer location.

Features Not Included

There are features that were not included in the ALBE visibility model because of limited resources. These features include the integration of variable sensor types, such as night vision goggles or infrared. Target background and contrast algorithms should be implemented with the acuity algorithm to show that a green truck could be seen in front of a sand dune, but not in front of a forest. Atmospheric attenuation algorithms should be included so that the absorption and scattering due to smoke, haze, humidity, and other atmospheric effects would be considered. The current model assumes a crystal clear air space between observer and target. Other enhancements such as sun shadowing effects would be of benefit. A technical report by Chen, Try, and others gives a comprehensive description of these proposed enhancements.

VISIBILITY RELATED PRODUCTS

How High to Visibility Product

The ALBE visibility algorithm creates other products besides those providing the basic "visible" vs "hidden" areas. It also creates what is known as a "How High" product. This product further contours the hidden areas into delineated regions showing the distance the target would need to be raised to create visibility with the observer. These "How High to Visibility" values allow the user to distinguish between a shallow hidden region where a target needs to be raised only 5 meters to create visibility and a deep hidden region where the target could be raised 500 meters and still remain hidden.

Radio Frequency Loss

Another product of the ALBE visibility model is estimated Radio Frequency Loss. The Terrain Integrated Rough Earth Model (TIREM3) from the Electromagnetic Compatibility Analysis Center (ECAC) was incorporated into the ALBE visibility model. This product shows the effects that terrain and other factors have on communications by estimating the radio frequency loss (in decibels) for a given transmitter frequency. The TIREM Programmer's Reference Manual written by Sciandra contains a more detailed look at the TIREM model.

Visibility Probability

The ALBE visibility model also provides what is called a "Visibility Probability" product. Most visibility algorithms will classify an area as either 'hidden' or 'visible', ignoring the error variances associated with elevation values. The visibility probability algorithm will further delineate these two regions into 'definite' and 'probable' categories. The result is that the user can more easily identify regions that are borderline in their designations as either "visible" or "hidden" areas. These areas should be treated more carefully from those where a high level of confidence exists.

A relative accuracy value for the elevation values is needed to calculate visibility probability. This value within ALBE is provided by user input. If a target is initially calculated as being visible, the relative accuracy value is <u>subtracted</u> from the target height, as shown in Figure 17. The line-of-sight angles are then recomputed. If the new target is still visible, it is classified as "definitely visible." If the new target is now hidden, it is classified as "probably visible."

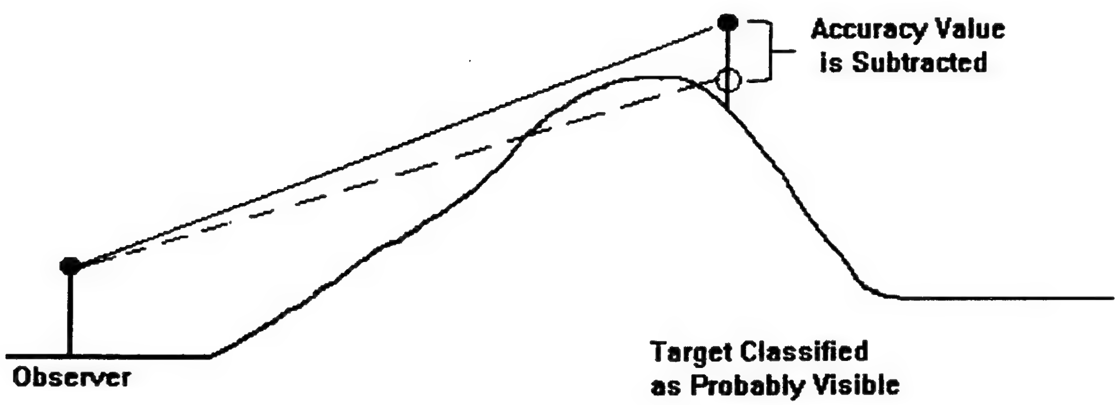

Figure 17. Target Is Marked As Probably Visible.

For targets that are initially classified as "hidden," the relative accuracy value is <u>added</u> to the target height and the line-of-sight angles recomputed, as shown in Figure 18. If the new target is now visible, it is classified as "probably hidden." If still hidden, it is classified as "definitely hidden."

Because of the important role that visibility analysis provides for military applications, it is essential that more models consider the known inaccuracies included within the standard data bases. Rather than computing only true/false values or providing precise values, it may be more important to give confidence ranges for these results. The visibility probability product is one way of providing this information.

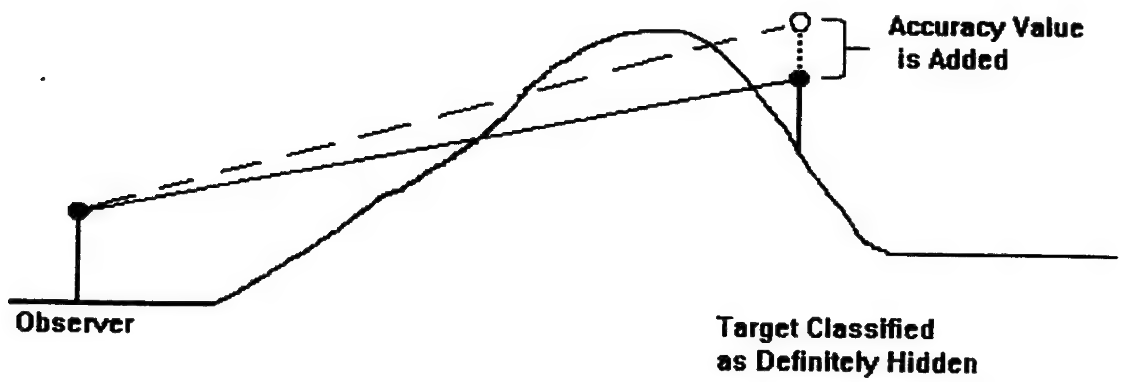

Figure 18. Target Is Marked As Definitely Hidden.

Line of Sight for Obstructions

There are a series of tactical decision aids that use the basic algorithms and concepts of the ALBE visibility model. The first of these spinoff models was the Line of Sight for Obstructions, illustrated in Figure 19. In this model, the user enters the observer height and an angle from the observer position. The algorithm looks out along this angle to see if the terrain obstructs this path. A contour line will show if any obstructions exist. An example of how this model could be used would be in determining possible sites for a mobile missile defense system.

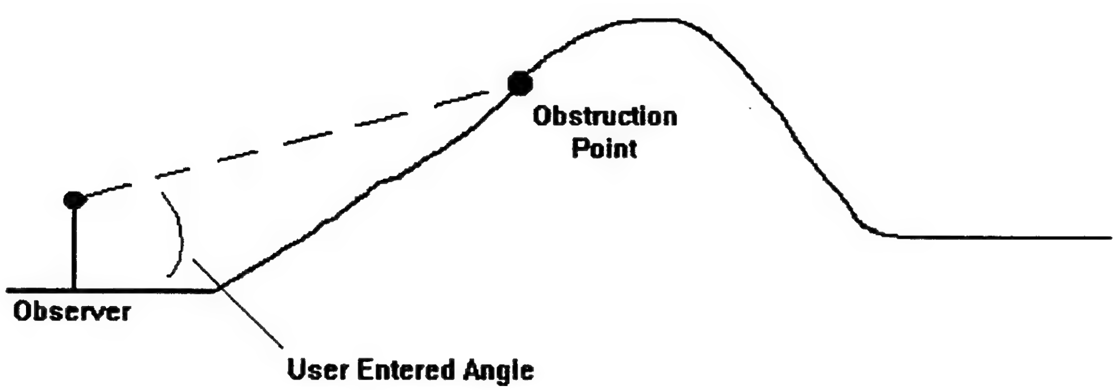

Figure 19. Line Of Sight For Obstructions Shows Where Terrain Intersects Observer Angle.

Aerial Detection

The aerial detection model, illustrated in Figure 20, is used to show where incoming aircraft can first be detected by the central observer. The user can adjust the altitudes of the incoming aircraft and choose whether the aircraft is flying at a constant elevation above sea level or at a constant height above the terrain. Output consists of contour lines showing the distances at which aircraft first become visible to the center observer.

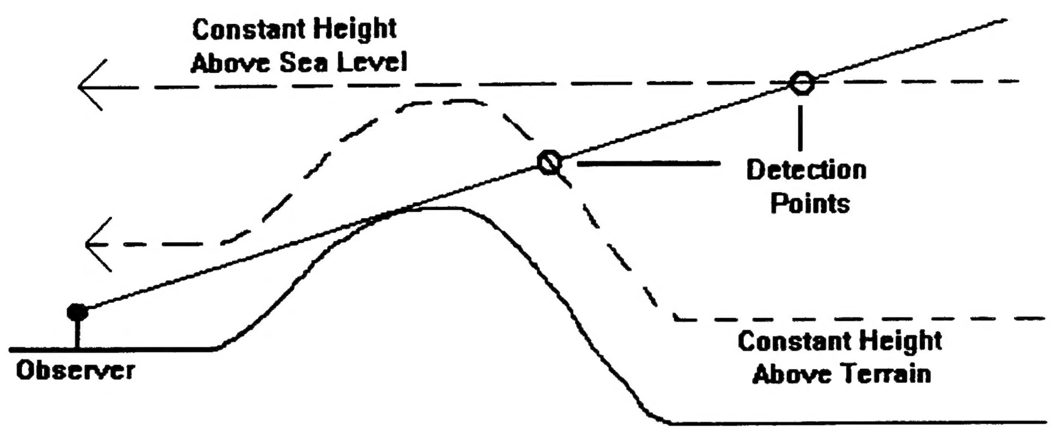

Figure 20. Aerial Detection Shows Points Where Incoming Aircraft Is First Detected.

Helicopter Approach Zones

Another related model is the Helicopter Approach Zones model. This model determines the areas a helicopter must stay away from to avoid direct fire from a centrally located target and the suitable areas where a helicopter can approach a target undetected. Optimal positions where a helicopter can pop up from a hidden position, fire its missiles, and drop back down to safety are designated, as shown in Figure 21. Best positions will be those as shown in Figure 22, where the target cannot easily detect a helicopter in pop-up firing position because the helicopter is not silhouetted against an open sky backdrop. This model can be useful in planning the safest flight lines for a helicopter.

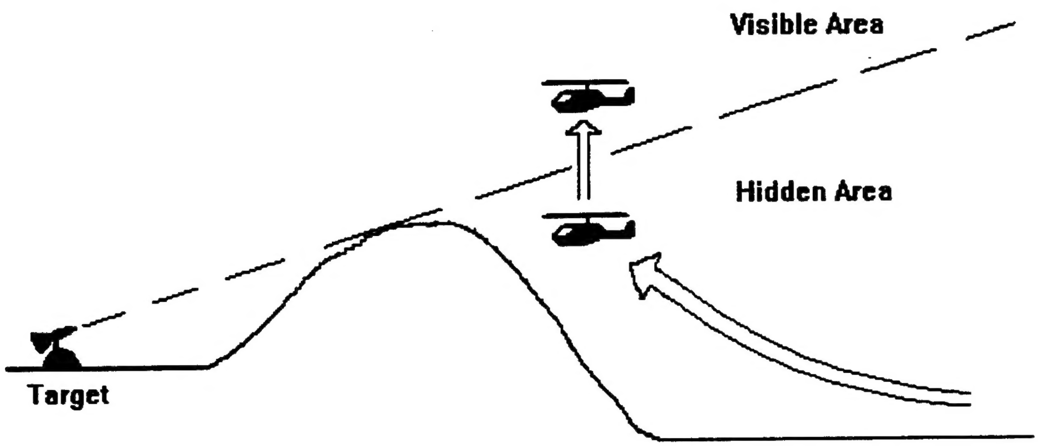

Figure 21. Helicopter Fire Position With No Suitable Backdrop.

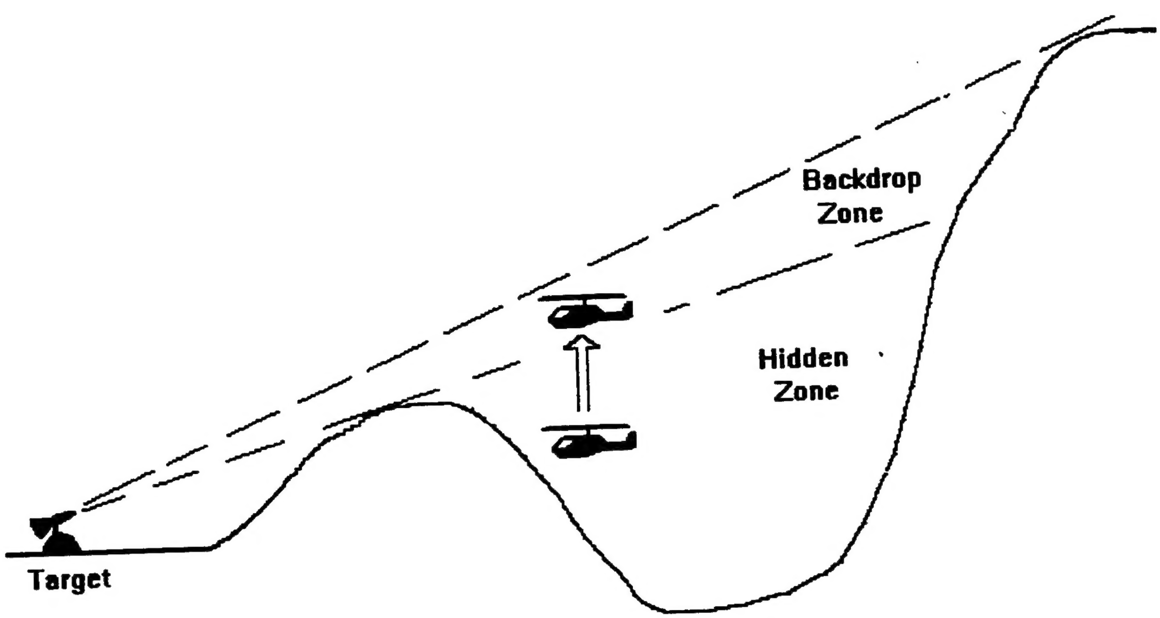

Figure 22. Helicopter Fire Positions With a Suitable Backdrop.

CONCLUSIONS

There are many different methods of calculating visibility products. The ALBE gridded visibility model provides a fast and accurate model whose product output can be easily integrated within other models or systems. New methodologies were developed to give the best fit for the concepts of

1. Grid cell resolution.

2. Spacing between radials.

3. Spacing along radials.

which all use the gridded raster approach. Other features such as earth curvature, vegetation, visual acuity, and an elevation matrix form have also been included in the model. Many of the concepts used within the basic gridded visibility model were also used in other visibility related TDA's. Ideas and concepts developed while generating this algorithm should assist future visibility line-of-sight algorithm developers in understanding the potential risks and benefits involved.

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